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EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

REPORT No. 21/R/61

Measurement of the Burning Surface Temperatures of Propellant Compositions by Infrared Emission

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    Essex.

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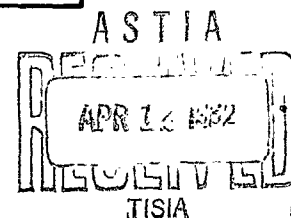
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Measurement of the Burning Surface Temperatures
of Propellant Compositions by Infrared Emission

by

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ESSEX

CONTENTS

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1. SUMMARY

The temperatures of extremely thin surface layers of burning solid propellant compositions have been determined by measurement of their infrared radiation. Specific wavelengths, at which the flame gas emission is low, have been selected for the measurements. The path length of the radiating gaseous flame through which the surface is viewed has been reduced using a specially designed burner so that adequate correction for gas emission can be made. The surface temperatures of ammonium perchlorate compositions have been examined in some detail and the effect of the magnitude of the absorption coefficient of the material on the observed temperature has been demonstrated with this system. For example, at wavelengths at which the absorption coefficient is low, the surface temperatures of very weak fuel/ammonium perchlorate powder mixtures appear to fall somewhat as the burning rate increases but in spectral regions of suitably high absorption coefficient the surface temperatures remain virtually constant, irrespective of the burning rate. The surface temperature for such mixtures burning at atmospheric pressure, is $495^\circ \pm 15^\circ C$. Practical propellant compositions, based on ammonium perchlorate and containing rather more than stoichiometric proportions of fuel, give the same temperature provided that the hot gas emission can be successfully eliminated, but observed temperatures are in some instances raised (to a maximum of about $560^\circ C$) by gas interference. It is concluded that the process taking place at the burning ammonium perchlorate surface is an equilibrium sublimation process and that the rate of consumption of the solid is controlled by subsequent gas phase reactions among the dissociation products.

The average surface temperature of double-base propellants increases with increase of burning rate, although it is likely that the liquid nitric ester component vaporises at constant temperature. The retention of carbonaceous products near the burning surface of some compositions makes measurements of surface temperature inaccurate and has so far prevented the determination of the precise temperature dependence of the nitrocellulose decomposition. Double-base compositions have surface temperatures ranging from 300° to $400^\circ C$ at atmospheric pressure. Binder-fuels currently used in composite propellants have surface temperatures close to $500^\circ C$ when burning in a diffusion flame with oxygen.

2. INTRODUCTION

Attempts to measure the burning surface temperature of solid propellants have almost invariably failed because of the experimental difficulties which derive from the extreme thinness of the overall flame zone, including the surface, in which temperature gradients of many thousands of degrees per millimetre can exist. This paper describes a method of obtaining the burning surface temperature by measurement of the intensity of radiation from the surface at selected wavelengths in the infrared region. The method was developed for the study of the surface temperature of burning ammonium perchlorate and the technique is demonstrated using compositions based on this oxidiser, but its application is not limited to these compositions and some results for double-base propellants and liquid monopropellants are included.

3. EXPERIMENTAL METHOD

3.1 Quantities to be Measured

The temperature of a blackbody radiator, b, may be calculated from Planck's Law if its spectral radiant intensity, $J\lambda$, at any wavelength λ is known.

$$(J_b)_\lambda = AC_1\lambda^{-5}/\{\exp (C_2/\lambda T_b)-1\} \qquad \ldots\ldots \underline{1}$$

where A = area, cm^2,

C_1 = first radiation constant,

C_2 = second radiation constant, 1.438 cm. deg,

λ = wavelength, cm,

T = absolute temperature, $^\circ K$,

For a radiator, a, which is not a blackbody, knowledge of the spectral emissivity, ϵ_a, of the radiator at the wavelength concerned is an additional requirement for the calculation of its temperature.

$$(J_a)_\lambda = (\epsilon_a)_\lambda AC_1\lambda^{-5}/\{\exp (C_2/\lambda T_a) - 1\} \qquad \ldots\ldots \underline{2}$$

Since absolute measurements of radiant intensity are, in practice, difficult to perform, it may be preferable to determine the relative radiant intensities from the blackbody at known temperature and non-blackbody in order to arrive at the temperature of the latter.

$$\frac{J_a}{J_b} = \frac{\epsilon_a[\exp (C_2/\lambda T_b)-1]}{\exp (C_2/\lambda T_a)-1}$$

$$T_a = 0.621/\lambda \log \left\{\frac{J_b\epsilon_a}{J_a} [\exp (C_2/\lambda T_b)-1] + 1\right\} \qquad \ldots\ldots \underline{3}$$

Wien's Law expresses the energy distribution of radiation less precisely than Planck's Law at long wavelengths but was found to be sufficiently accurate for the determination of temperature from relative radiant intensities up to ~10μ provided that the temperature of the reference blackbody was set to within about 30°C of the temperature of the surface to be measured. The temperature is then more quickly calculated from Wien's Law:

$$J_\lambda = C_1\lambda^{-5} \exp (-C_2/\lambda T) \qquad \ldots\ldots \underline{4}$$

$$\left(\frac{J_a}{J_b}\right)_\lambda = \epsilon_a \cdot \exp (-C_2/\lambda T_a)/\exp (-C_2/\lambda T_b)$$

$$1/T_a = 1/T_b - 1.610\lambda \log (J_a/J_b\epsilon_a) \qquad \ldots\ldots \underline{5}$$

Provided an accurate comparison of the energies from the radiating surface and blackbody can be made and T_b, ϵ_a, and λ are known, it is seen that the temperature of a surface can be readily calculated. Particular problems are, however, encountered when attempting to obtain a reliable measure of J and ϵ_a for a surface which is burning.

/The .....

The first difficulty is that the surface is enveloped by a layer of very hot gas which is itself radiating; it is therefore essential that the emission from the surface and from the hot gas be distinguished. Secondly, there is the uncertainty regarding the emissivity of the thin radiating layer of the propellant surface, with its steep gradient of temperature into the interior of the propellant. These factors will be considered below.

3.2 Measurement of Radiant Intensities of Surface and Blackbody

At the surface temperatures likely to be encountered, the most sensitive wavelength regions in which to measure surface radiation should be in the near infrared and it was found that there was, in fact, sufficient energy from almost all of the propellants examined to allow the use of a conventional Grubb-Parsons infrared spectrometer with a sodium chloride prism for the comparison of radiant intensities. The optical system used for the comparison of the various sources is depicted in Fig. 1. Radiation from the burning propellant surface, from the heated but unignited surface, or from the blackbody could be collected through an identical optical system by rotation of the plane mirror, $\underline{M}$, thereby ensuring equal instrument losses from each source.

The reference blackbody radiator located in the centre of the furnace was constructed of oxidised stainless steel and consisted of a cylindrical cavity with a small observation slot in one end. The end of the cylinder facing the slot was filled with a "honeycomb" made from a roll of alternately plain and crimped thin steel tape, so that any direct radiation from the back surface of the cavity also came from the multiple cavities of the "honeycomb". The temperature of the blackbody was recorded by a Pt/Pt-Rh thermocouple located in the face of this "honeycomb". A diagram of the blackbody is included in Fig. 1.

3.3 Measurement of the Spectral Emissivity of the Propellant Surface

The determination of the spectral emissivity, ϵ_λ of an actively burning surface is most difficult, so values obtained at temperatures below the spontaneous ignition temperature of the composition had to suffice. The validity of using low-temperature emissivities in the estimation of burning surface temperature, has to be established subsequently by determination of the latter at various values of λ and the appropriate experimental value of ϵ_λ.

The spectral emissivities of ammonium perchlorate and cordite compositions were determined by slowly heating a thin slab of the composition in a rising stream of hot air to a steady temperature somewhat below the spontaneous ignition temperature; the energy emitted (in a direction normal to the surface) was related to that emitted from the blackbody. The temperature of the sample was recorded, using a fine thermocouple embedded in the surface. The emissivity was calculated from Planck's Law.

$$\left(\epsilon_a\right)_\lambda = \left(J_a/J_b\right)_\lambda \cdot \exp\left(C_2/\lambda T_a\right) - 1/\{\exp\left(C_2/\lambda T_b\right) - 1\} \qquad \ldots\ldots \underline{6}$$

With careful heating the emissivity of ammonium perchlorate could be determined at temperatures beyond the first exothermic decomposition (270°C) but spontaneous ignition usually occurred above $\sim 360^\circ$C. Variation of emissivity with temperature over the range 200 to 360°C was within the maximum experimental error of about $\pm$ 6 per cent and no extrapolation was necessary for the use of these values at burning surface temperatures ($\sim 490^\circ$C).

The emissivities obtained in this way, with a thick, uniformly-heated layer of material, are only useful in the determination of burning surface

- 3 -

temperatures of somewhat "transparent" substances if the depth of heating is sufficiently large. The emissivity, ϵ_x, for thin layers (not opaque) of material is related to the emissivity of thick (opaque) layers according to

$$\epsilon_x = \epsilon \{exp. (- kx)\} \qquad \qquad \cdots\cdots \underline{7}$$

where ϵ_x = emissivity of layer x cm. thick,

ϵ = measured emissivity (opaque layer),

k = absorption coefficient of the material,

since by Kirchhoff's law, the emissivity, the reflectivity, r, and the absorption coefficient must be related:

$$\epsilon_\lambda = (1 - r)(1 - exp \{- kx\}) \qquad \qquad \cdots\cdots \underline{8}$$

The optimum wavelength for the determination of the average temperature of a thin element of burning propellant surface is therefore that at which the reflectivity is low and the absorption coefficient is high; such a condition usually occurs at wavelengths at which molecular vibrations are excited, and is demonstrated in Figures 2 and 3. Fig. 2(a) shows the emissivity of ammonium perchlorate both as an optically thick slab and as a thin film deposited on to a sodium chloride plate by vacuum sublimation. The infrared transmission of the same thin film is given in Fig. 2(b). The emissivity of the thin film had to be determined at a rather low temperature in order to minimise the exchange reaction:

$$NH_4ClO_4 + NaCl \rightarrow NH_4Cl^\uparrow + NaClO_4$$

Above about 250°C the NH_4Cl was rapidly eliminated from the surface, leaving only $NaClO_4$. Favourable wavelengths for temperature determination of thin layers are seen to be in the 3, 7 and 9μ regions. Taking values of absorption coefficients estimated from the transmission of ammonium perchlorate solutions (in pyridine) and from pressed discs of the solid, a rough estimate can be made of the minimum thickness of the heated layer required for the emissivity of that layer to be within, say 5 per cent of the measured emissivity for the bulk material. These thicknesses are roughly 0.8, 1.5 and 2μ at the highly absorbing wavelengths 9.2, 7.1 and 3.1μ respectively and 20μ and 200μ at the less strongly absorbing wavelengths 4.98 and 2.25μ. Provided emission from the gaseous flame and atmospheric absorption is not strong at the first three wavelengths above, they should be useful for the determination of the average temperature existing within a few microns of the propellant surface. Figure 3 gives emissivity and transmittance data for optically thick and optically thin layers of nitrocellulose (12.6 per cent N, 1 per cent stabiliser) and indicates that the most favourable wavelengths for surface temperature measurements are, in this case, at 6.05, 7.8 and 9.3μ.

3.4 Emission from the Gas Phase

Radiation from the very hot gaseous flame enveloping the propellant surface has to be eliminated if a reliable measure of the intensity radiated from the surface itself is required. Two methods have been combined to achieve this end. Firstly, a wavelength is chosen at which the gas phase radiation is low relative to that from the surface, and secondly the depth of emitting gas is sharply restricted by the use of a special burner in which the products are rapidly sucked away sideways from the burning surface. The suction must be variable so that it can be adjusted to be sufficiently strong to remove the gas flame yet not interfere with the stability of the

combustion.   Fig. 1 b.c indicates the essential features of the burner.
Fig. 4 compares the infrared emission from about 1 cm depth of the gaseous
products (at 1240°C) from a weak fuel/ammonium perchlorate composition, burning
at atmospheric pressure, with that from the burning surface, viewed through
approximately 2 mm of the flame gases.   In the special burner the flame
envelope can normally be reduced to 2 mm or less and it can be seen from Fig. 4
that the gas contribution to radiation can, at selected wavelengths, be kept
very low.   In practice, the gas contribution of the small layer of the flame
gases enveloping the surface is estimated in each experiment and deducted from
the measured radiation.

3.5   The Measurement of a Burning Surface Temperature

The infrared spectrometer is set at a wavelength at which the conditions
of emissivity and gas emission of the propellant are favourable.   The mirror,
M, (Fig.1) is sighted on the blackbody source, maintained at a temperature
near that of the surface, and the radiant intensity measured at a suitable
slit-width.   The mirror, M, is then sighted on to the unignited propellant,
loaded to a depth of 1 cm or more in the special burner with the propellant
surface normal to the line of sight.   The propellant is ignited and the radiant
intensity recorded, with the same spectrometer settings as for the blackbody,
as the propellant burns down in the container.   The flame gases are cut off
sharply by the suction at the mouth of the tube, but the depth of emitting gas
increases as the propellant recedes;   extrapolation of the recorder trace to
zero time after ignition gives the surface emission without contribution from
the gas.

4.   SURFACE TEMPERATURES OF PROPELLANT COMPOSITIONS BURNING AT ATMOSPHERIC PRESSURE

4.1   Ammonium Perchlorate Compositions

Ammonium perchlorate will undergo self-sustained flame decomposition at
atmospheric pressure if sufficient fuel or preheat is provided to give a final
flame temperature of 930°C or more [1];   at higher pressures no extra heat is
required.   The precise nature of the flame decomposition process of ammonium
perchlorate is of vital importance in the combustion of propellants based on
this oxidiser, since it exercises a dominating influence on the overall combustion
rate and its pressure dependence.   It is commonly postulated that the rate of
consumption of the ammonium perchlorate is controlled by its surface temperature [2]
and it has been a main objective of the present experiments to discover the
dependence of burning rate upon the measured surface temperature.   Powder
mixtures of ammonium perchlorate and readily gasified fuels have been used
extensively in these experiments, since it has been shown [1] that the burning
surface consists solely of decomposing ammonium perchlorate, the fuel component
of the mixture having been gasified, and probably considerably oxidised, well
below the visible surface.   The rate of burning has been varied by minor changes
in fuel concentration and by the addition of catalysts, the latter method
providing an opportunity of a large increase in the rate of consumption without
much change in the final flame temperature.   The surface temperature measure-
ments, summarised as a function of rate of burning in Fig. 5, are those obtained
at wavelengths at which the absorption coefficient of the (unignited) ammonium
perchlorate is high (See section 3.3).   The results in Fig. 6 are given to
demonstrate the effect of low absorption coefficient on the measured surface
temperature;[*]   the effective emissivity becomes lower as the burning rate

---

[*]Note: The ammonium perchlorate surface temperatures quoted [1] were mostly
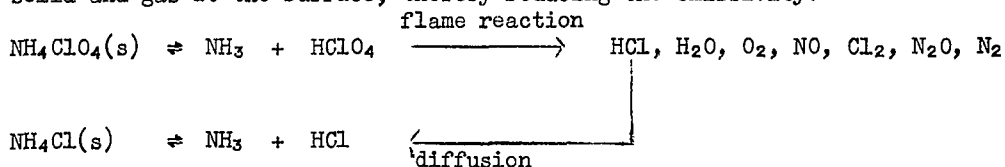determined at 4.98μ.

/increases .....

increases and the depth of heating of the surface decreases. In effect, the optical method sometimes "views" a layer of surface greater than the layer heated by the flame. In these cases the temperatures measured, which are always an average for the depth viewed, fall as the burning rate increases. At wavelengths of low absorption coefficient, the size distribution of the burning ammonium perchlorate particles affects the measured temperature (see Fig. 6) whereas in strongly absorbing regions this is not so (Fig. 5).

The surface temperature of ammonium perchlorate burning at atmospheric pressure is close to 490°C and does not increase significantly with rate of burning. The rate of consumption of the solid cannot, therefore, be controlled by the temperature of the surface but is more probably governed by the gradient of temperature established there by the gas-phase flame reaction. The reaction at the surface is assumed to be the equilibrium process:

$$NH_4ClO_4(s) \rightleftharpoons NH_3(g) + HClO_4(g) \quad \Delta H = 56 \text{ kcal/mole}$$

so that the temperature of the solid salt is fixed essentially by the partial pressures of the dissociation products and is not influenced by change in its rate of heating or the temperature of its environment.

Catalysts, such as copper chromate, can increase the burning rate very considerably without changing the observed surface temperature/burning rate relationships; some points are included in Fig. 4 and 5. It is assumed that sufficient catalyst does not accumulate on the burning surface to alter its emissivity; the emissivity of copper chromate is less than ammonium perchlorate in the near infrared. The surface temperature/burning rate curve at 9μ resembles those obtained at the wavelengths 2.25 and 4.98μ at which the absorption is relatively weak and the apparent fall in temperature as the rate increases suggests that burning ammonium perchlorate is much less strongly absorbing, or reflects more strongly, at 9μ than experiments on the unignited material would indicate. It is the perchlorate ion which is responsible for the absorption at 9μ, whereas at 3.1μ and 7.1μ it is the ammonium ion, and it is possible that the former is replaced to some extent by the chloride ion (which does not absorb at 9μ) during the equilibrium processes occurring between solid and gas at the surface, thereby reducing the emissivity:

$$NH_4ClO_4(s) \rightleftharpoons NH_3 + HClO_4 \xrightarrow{\text{flame reaction}} HCl, H_2O, O_2, NO, Cl_2, N_2O, N_2$$

$$NH_4Cl(s) \rightleftharpoons NH_3 + HCl \xleftarrow{}_{\text{diffusion}}$$

Practical composite propellants, which usually contain just over stoichiometric proportions of fuel as a binder for ammonium perchlorate, yield surface temperatures little different from those for weak fuel/ammonium perchlorate powder mixtures given in Fig. 5. In the practical propellant compositions gas temperatures of 2700°C may be reached and the gas radiation is eliminated only with difficulty, so the surface temperatures may be subject to a small positive error. Table 1 gives the surface temperatures of some compositions burning at atmospheric pressure. As with the powder mixtures, the temperatures decrease slightly as the rates of burning increase, but the values at 9μ are not as low as would be expected by analogy with the latter, although low T_s values are still obtained at 4.98μ for these fast-burning compositions.

/TABLE 1 .....

TABLE 1

Surface Temperatures of some Composite Propellants Burning at Atmospheric Pressure

Oxidiser	Fuel Binder	Burning Rate, cm/sec	Surface Temperature ($^{\circ}$C) Determined at			
			3.1μ	7.1μ	9.0μ	4.98μ[†]
NH_4ClO_4	11% $(CH_2)_n$	0.094	561	550	508	(475)
"	"	0.120[‡]	530	514	504	(426)
"	"	0.135[‡]	542	513	499	(434)
"	"	0.148[‡]	500	497	498	(434)
NH_4ClO_4	24% Rubber[§]		500	508	492	(451)

[‡] Rate of burning increased by catalysts ($\sim$ 1%)

[†] "Transparent" wavelength

[§] Polyurethane rubber containing 25% nitric ester

    That the surface temperature measured in the ammonium perchlorate/fuel mixtures is essentially that of the perchlorate can be shown by burning the latter without added fuel. This can be done by preheating the salt to 250°C or more, or by burning in a gaseous fuel atmosphere, when the decomposition flame is augmented by heat from the diffusion flame between its products and the fuel atmosphere. In the latter situation, the surface has to be observed through the high-temperature diffusion flame and surface temperatures are liable to be slightly high (as were those for the high-temperature propellants) at wavelengths where some gas emission cannot be avoided. The apparent increases in surface temperature with fuel concentration (Table 2) are considered to be solely due to unwanted gas-phase emission. When ammonium perchlorate deflagration is assisted merely by preheating the salt the surface is 'viewed' through gases at relatively low temperature (around 1000°C) and little gas interference is experienced. The observed burning surface temperatures of pure ammonium perchlorate are given in the lower part of Table 2.

TABLE 2

Surface Temperature of Ammonium Perchlorate Burning in
Fuel Atmospheres and of the Preheated Material

Wavelength, μ:	2.25[†]	3.1	4.98[†]	7.1	9.2
Fuel/Gas Mixture	Surface Temperature, $^\circ$C				
$H_2:N_2$					
0.36:1	475	504	527	486	447
1.1:1	470	513	510	516	441
1.38:1	470	523	510	516	441
1:0	484	536	533	529	459
CH_4	475	522	510	498	442
Preheated [§] Ammonium Perchlorate	495	499	523	501	436

[†] "Transparent" wavelengths

[§] Preheated to 295-350°C

- 8 -

TABLE 3

Surface Temperatures of some Nitric Ester Compositions Burning at
Atmospheric Pressure

Wavelength, μ:		8	9.3	9.9
Composition	Burning Rate, cm/sec	Average Burning Surface Temperature, $^\circ$C		
HUK	0.15	409	397	380
SC	0.087	327	331	324
CSC$_{\frac{1}{2}}$K.	0.054	300	307	307
N.C.	0.045	304	--	--
N.G./C.A.	0.04	334	--	--
D.B./A.P.	0.16	441	443	--
G.D.N./T.A.	0.0023	217	--	--
G.M.N.	0.0067	186	--	--

Data on Compositions

	Nitrocellulose	Nitroglycerine	Diluent	Heat of explosion
HUK	56	43	3.2	1192
SC	49.5	41.5	9	965
CSC$_{\frac{1}{2}}$K.	50	35	15	745
N.C.	100(12.2%N)	0	0	912
N.G./C.A.	0	65	35 (cellulose acetate)	
D.B./A.P.	27.8	32.4	31 (ammonium perchlorate)	
G.D.N./T.A.	Glycol dinitrate 70, triacetin 30			
G.M.N.	Glycol mononitrate			

/4.2 .....

4.2 Propellants Based on Nitric Esters

The more volatile nitric esters have burning surface temperatures near
to their boiling points and the process taking place at the surface is solely
vaporization. Nitrocellulose, on the other hand, is involatile and the
burning of a mixture of this substance with a volatile nitric ester, e.g.
double-base propellant, is bound to be a complex, inhomogeneous process.
It can be readily observed that reaction at the surface is irregular and that
considerable temperature differences occur across the surface. Nevertheless,
knowledge of the average surface temperature has been of much interest and
several attempts have been made to arrive at useful values, mainly by indirect
methods. A brief review of such methods has been made (3). The results
given in Table 3 confirm those previous experiments which have indicated low
values for the surface temperature. For example, by measuring the amount
of heat in the surface layers of a suddenly extinguished piece of propellant,
Aristora and Leipunskii (3) obtained a value of $330° \pm 45°C$ for the surface
temperature of a double-base composition and $252° \pm 48°C$ for a single-base
nitrocellulose composition (both burning at atmospheric pressure). From
temperature profile measurements with very fine thermocouples, Klein et al. (4)
deduced that for a nitrocellulose composition (13.15 per cent N, 1 per cent
ethyl centralite) the surface is located in the profile at about $250°C$. These
measurements carried out at 350 - 700 p.s.i. would seem to conflict with those
of Daniels, Wilfong and Penner (5) who found temperatures exceeding $1000°C$ at
1500 p.s.i. Unless there is a strong dependence of surface temperature upon
the pressure, the results of the present work at atmospheric pressure favour
the lower temperature; the hottest composition quoted in Table 3 gives an
average surface temperature of only about $400°C$.

The double-base composition containing 31 per cent ammonium perchlorate
gave a surface temperature intermediate between that for a double-base
propellant and that for burning ammonium perchlorate.

In contrast to the ammonium-perchlorate-based propellants, the surface
temperatures of the double-base propellants increase as the burning rate
increases. An activation energy derived from the rate and the surface
temperature has little significance since the liquid component is probably
vaporizing from the surface and decomposing in the gas phase. A burning
mixture of glycol dinitrate and triacetin has a surface temperature intermediate
between the boiling points of the two ingredients, and glycol mononitrate has a
surface temperature close to its boiling point (Table 3). Attempts to
measure the burning surface temperature of pure nitrocellulose of various
nitrogen contents as a function of burning rate was frustrated by the formation
of carbonaceous products which built up on the surface.

5. SURFACE TEMPERATURE OF SOME BINDER-FUELS BURNING IN AIR AND OXYGEN

Surface temperatures of polymeric materials burning in diffusion flames
can be measured only approximately by the infrared emission method since
accurate correction for contribution of the flame envelope, which must be
left undisturbed, is difficult. With organic compounds burning in air the
flame interference at the selected wavelengths is usually not significant
but in undiluted oxygen the correction to the surface temperature may be
$-20°$ to $-50°C$. Some uncorrected surface temperatures for polymeric materials
burning in air and oxygen are given in Table 4; similar temperatures
probably obtain at the binder surface in composite propellant mixtures, so
it happens that with ammonium-perchlorate-based compositions burning at
atmospheric pressure the surface temperatures of both fuel and oxidiser
are close to $500°C$.

/TABLE 4 .....

- 10 -

TABLE 4
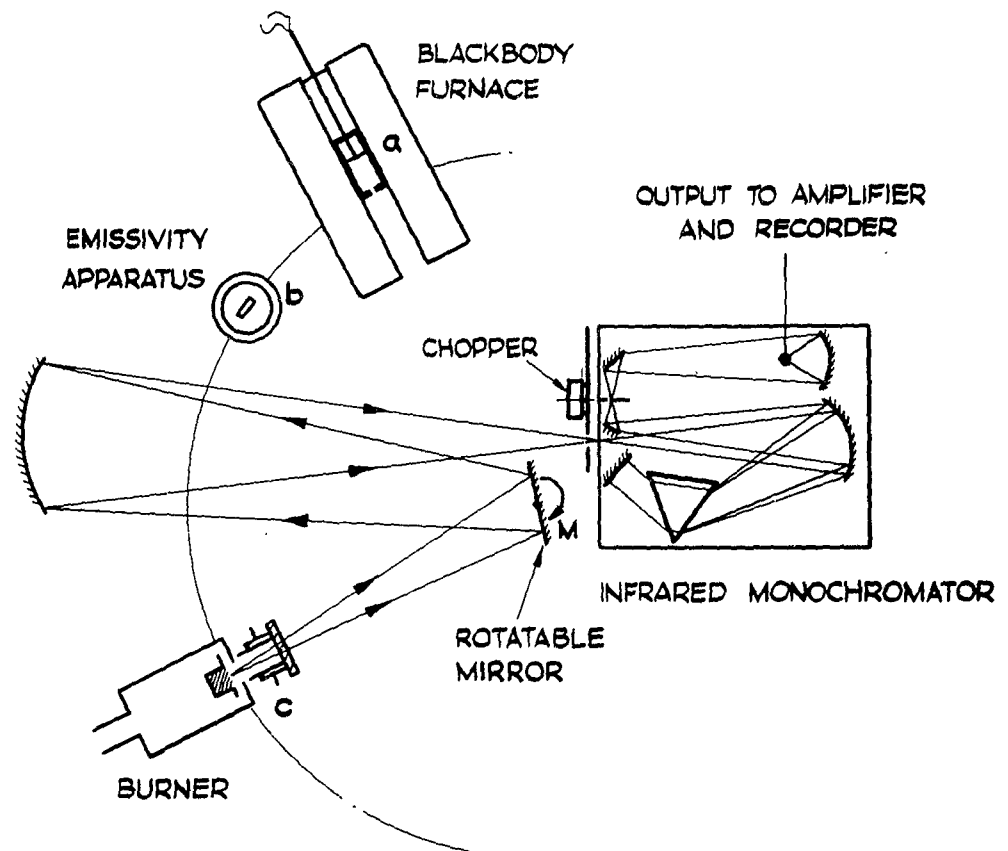
Burning Surface Temperatures of some Binder-Fuels

Fuel	Wavelength of the Determination, μ	Surface Temperature, °C	
		in Air	in O_2
Polythene	6.9	511	570
Polyisobutene	6.9	428	469
Polyester – Polyurethane rubber	8.75	unstable	507
Polypropylene glycol-polyurethane rubber	8.75	unstable	492
Polymethylmeth-acrylate	8.75	417	477 – 490

* Temperature somewhat dependent on flow rate

6. BIBLIOGRAPHY

1. Arden, E.A., Powling, J., and Smith, W.A.W., E.R.D.E. Report No. 4/R/61

2. Schultz, R.D., Green, W., and Penner, S.S.,
   "Combustion and Propulsion," 1958, Pergamon Press, New York, pp 367 – 420

3. Ed. Lewis, B., Pease, R.N., and Taylor, H.S., "Combustion Processes",
   1956, Oxford University Press, p.536

4. Klein, R., Menster, M., von Elbe, G., and Lewis, B.,
   J. Phys. Colloid Chem. 1950, 54, 877

5. Wilfong, R.E., Penner, S.S., and Daniels, F., ibid., 863.

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BLACKBODY
FURNACE

a

EMISSIVITY
APPARATUS

b

OUTPUT TO AMPLIFIER
AND RECORDER

CHOPPER

INFRARED MONOCHROMATOR

M

ROTATABLE
MIRROR

BURNER

c

OPTICAL ARRANGEMENT

LAYOUT OF THE APPARATUS.   FIG. 1a.

METAL 'HONEYCOMB'

THERMOCOUPLE

FURNACE

OBSERVE

CAVITY

a. BLACKBODY

HOT AIR COLUMN

HEATED SAMPLE

THERMOCOUPLE

OBSERVE

AIR

ELECTRIC AIR HEATER

b. EMISSIVITY APPARATUS

RAPID EXHAUST

ROCKSALT WINDOW

PROPELLANT

OBSERVE

BURNING SURFACE
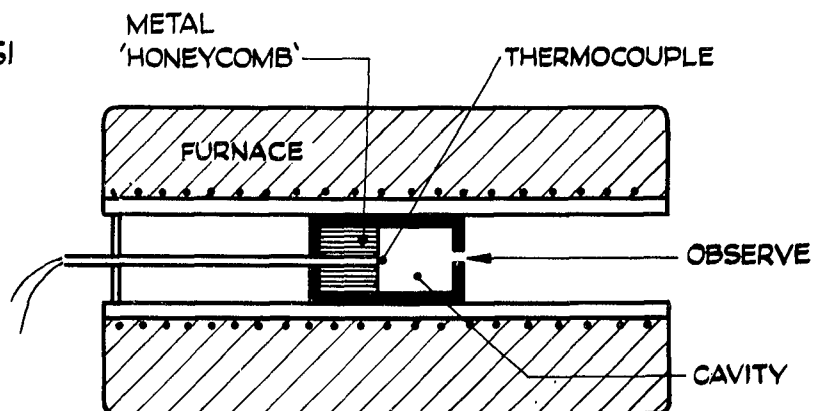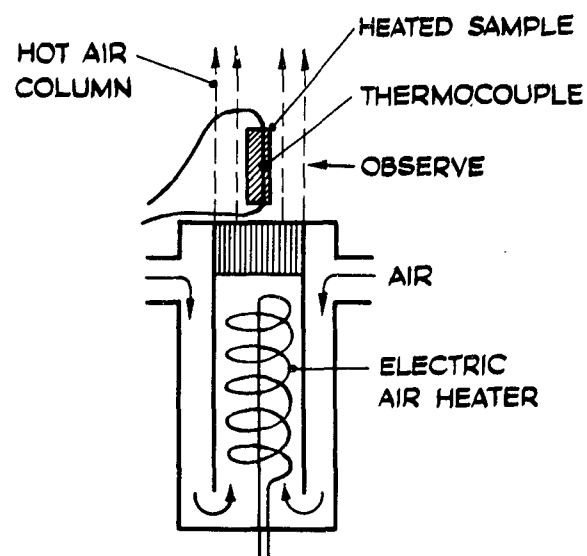
AIR OR FUEL GAS
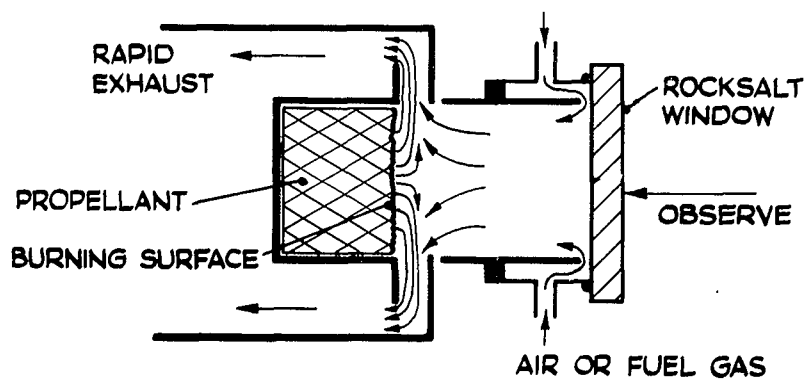
c. BURNER

DETAILS OF THE APPARATUS.   FIG. 1b.

(a) EMISSIVITY

AVERAGE VALUES FOR
THICK LAYER OF PRESSED
POWDER AT 200-360°C.

VERY THIN FILM AT 129°C
ESTIMATED THICKNESS,
0·0001 cm

(b) TRANSMITTANCE

SAME VERY THIN FILM
(0·0001 cm)

PRESSED DISK,
0·008 cm THICK.

WAVELENGTH , MICRONS
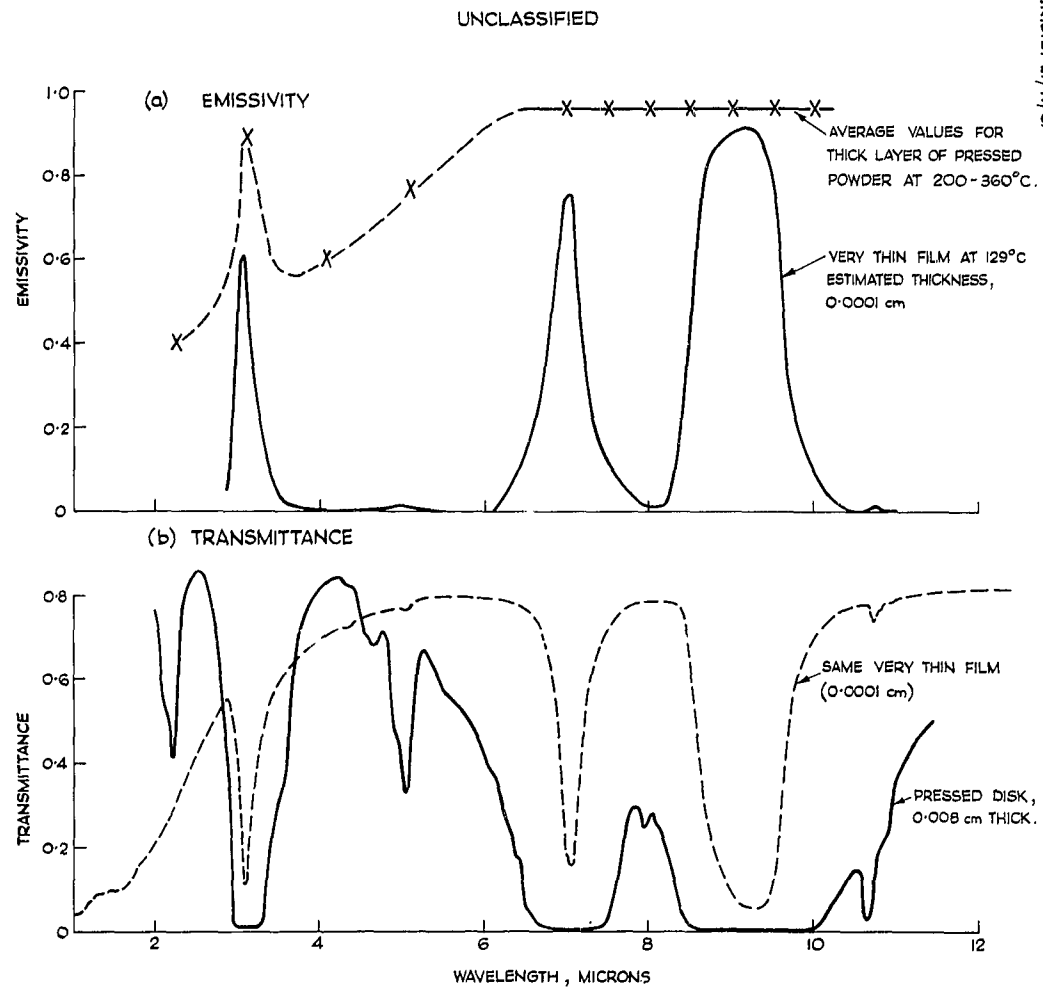
EMISSIVITY   AND   TRANSMITTANCE   OF   AMMONIUM   PERCHLORATE.   FIG. 2.
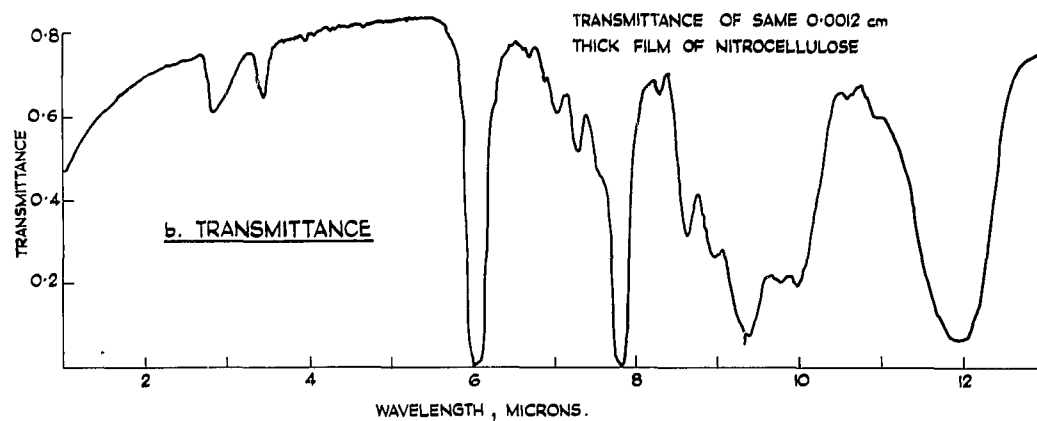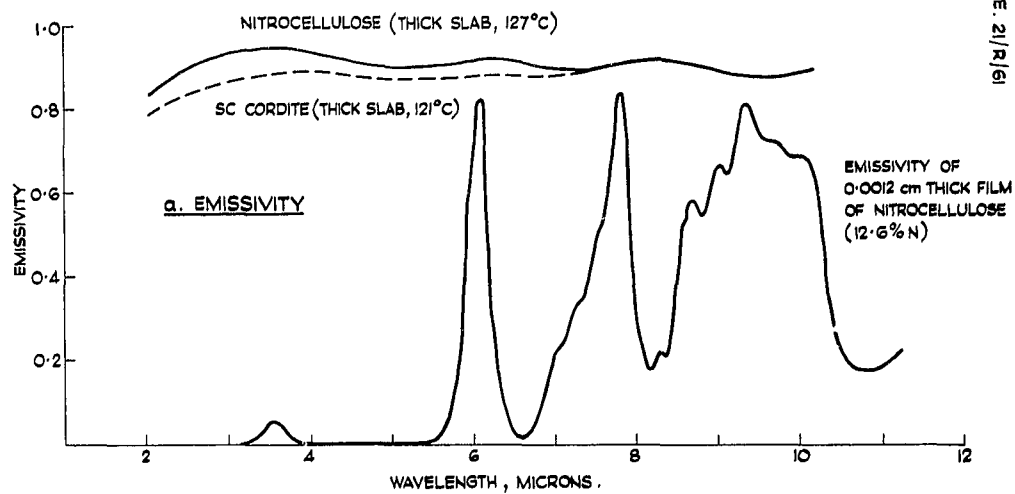
EMISSIVITY AND TRANSMITTANCE OF NITROCELLULOSE FILM.   FIG. 3.
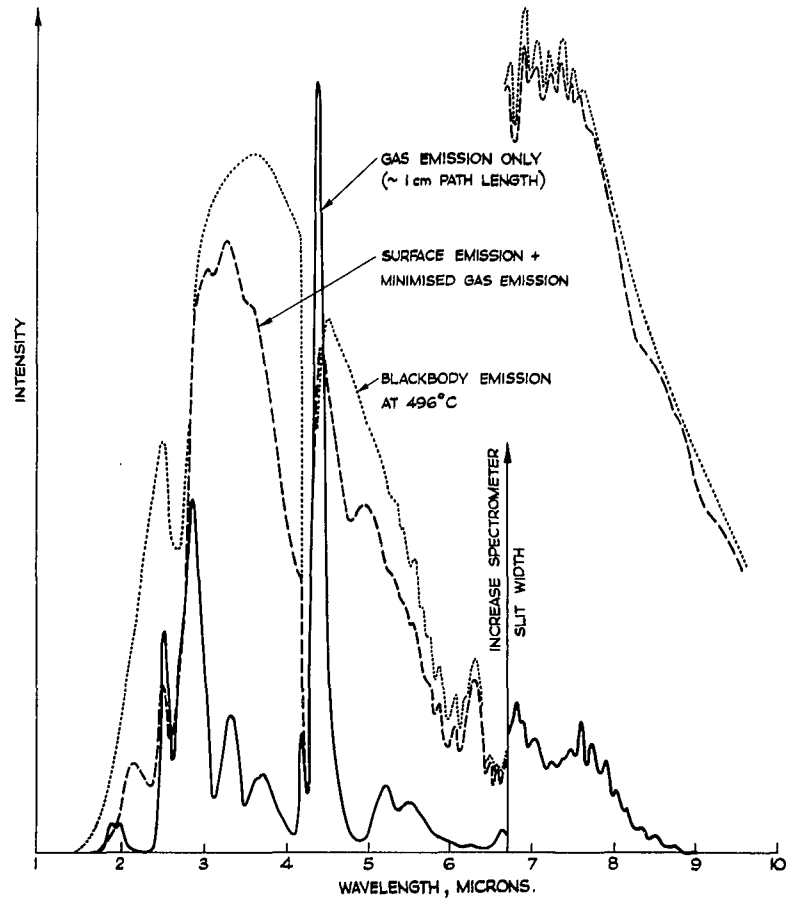
RELATIVE INFRARED EMISSION FROM TYPICAL AMMONIUM PERCHLORATE SURFACE, FLAME GAS AND BLACKBODY.   FIG. 4.

E.R.D.E. 21/R/61
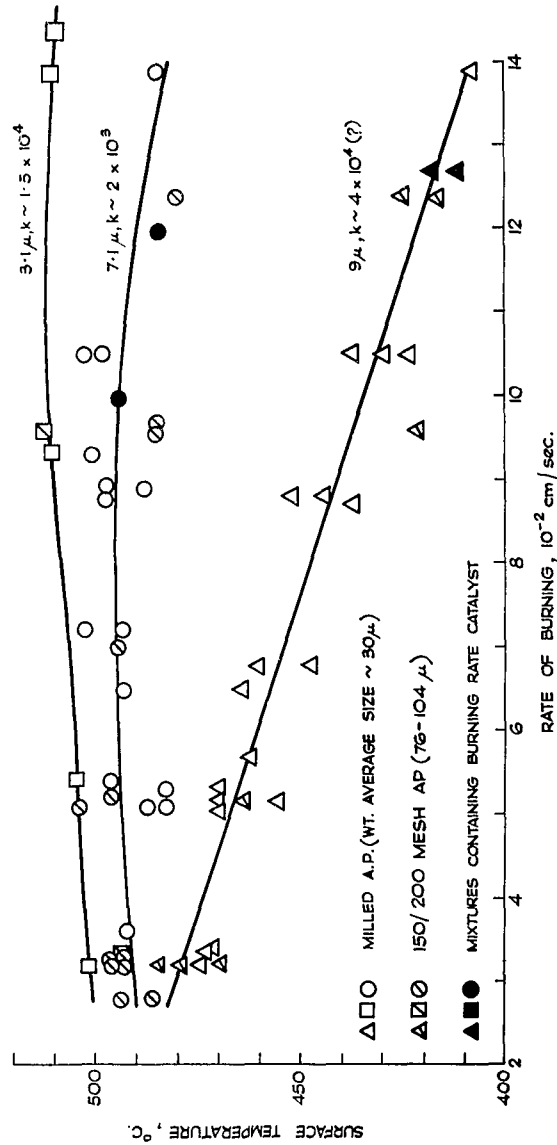
BURNING SURFACE TEMPERATURES AND REGRESSION RATES OF WEAK FUEL / AMMONIUM

PERCHLORATE MIXTURES.

FIG. 5.

APPARENT SURFACE TEMPERATURES OBSERVED AT WAVELENGTHS OF LOW ABSORPTION COEFFICIENT.

FIG. 6.

E.R.D.E. Report   Measurement of the Burning Surface Temperature of
No. 21/R/61   Propellant Compositions by Infrared Emission

J. Powling and W.A.W. Smith   March, 1962

A method of determining the burning surface temperatures of solid propellant compositions by measurement of the infrared emission from the surface is described.   Specific wavelengths, at which the solid emission is high and the gas emission is low, have been selected for the measurements. Very weak fuel/ammonium perchlorate powder mixtures, burning at atmospheric pressure have a constant surface temperature of $495^{\circ} \pm 15^{\circ}$C irrespective of the burning rate.   Practical propellant compositions, containing rather more than stoichiometric proportions of fuel with ammonium perchlorate, give a similar temperature provided that the hot gas emission can be successfully eliminated, but interference from the gas leads to maximum measured temperatures of about 560°C.   The average surface temperature of a double-base propellant increases with burning rate;   temperatures rang from 300° to 400°C at atmospheric pressure.   Binder fuels currently used in composite propellants also have surface temperatures close to 500° when burning in a diffusion flame with oxygen.

11 pp., 6 fig., 4 tables

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